**Model and constraints**

List of parameters:

Bmax: Maximum power rating of battery

Cbatt: Battery storage capacity

P1: prices in market 1

P2: prices in market 2

P3: prices in market 3

b1, b2, b3: battery schedule in each of the three markets 1,2, and 3

N: number of days for which the problem is solved

In a single day, the model looks like:

For simplicity the constraints are divided into the constraints for each day, which is divided into 48-time blocks.

1. Battery constraint on power limit
2. Constraint on battery soc

For the Soc constraint the initial soc (soc0d) is taken and then the sum of the battery schedule till that time is subtracted for each day

1. For each day, the battery capacity is taken as:

Where,

The number of cycles is calculated by dividing the total energy exchanged by the battery (sum of charge and discharge, obtained by taking the sum of absolute values of power).

Completing the model all at once, takes a long time to compile and run and likely gives a memory error on local machine. Hence, for simplicity each day has been analysed separately. The last Soc for previous day, becomes the starting soc for the next day.

1. The battery can have a total of 5000 cycles. Thus, the constraint:

Is modelled as:

Where N is the total number of days for which analysis is done. This ensures that the battery lasts for all of three years. The above modification makes the solution suboptimal, but allows a feasible and computationally efficient way to find the solution. As analyzing all the data for all three years was proving to be extremely computationally heavy.

**Notes and comments**

* The overall profit and revenue are given at the bottom of the excel sheet (rows 52610 to 52613)
* The battery uses almost 4360 charge-discharge cycles
* The annual operational profits (discounting capital installation cost) are given in sheet3
* In some cases, the batteries total power is nearly zero but some power is bought from one market and sold to another. In this case, this power will not go through the battery physically is bought from one market and directly sold to another. For example, at 1/1/2018 05:30 the following is the battery share in each market



* Power is purchased from market 3 and sold into market 2 (market 1 volume is near zero). If such a situation must be avoided the following constraints have to be added
* This ensures that power is either only bought or only sold in all three markets. However, adding the above constraint makes the problem non convex and more computationally difficult to solve hence this market arbitrage (buying from one market and selling to another) is assumed to be allowed.
* The data on efficiency is not used and battery is 100 % efficient. Including battery efficiency constraints makes the problem non convex and non-differentiable (solvable but computationally heavy). The way efficiency can be modelled is:

Where *bout*  is the power from battery to grid (positive for discharge, and negative for charging) and *batt* is the total charge / discharge power from the grid.

**Packages and libraries used**

* cvxpy: open-source convex optimization solver for python
* Convex programming is used instead of linear programming due to constraints around battery charge discharge cycles
* pandas and xlwings: for reading data from Excel files
* matplotlib: plotting the data in python

The programming language used is python and the code is written in a jupyter notebook for easy interaction and visualization.